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Trend analysis of water quality in the River Sabarmati from 2012 to 2023 using CPCB data

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ABSTRACT

River Sabarmati is an important freshwater resource in Gujarat and is subjected to various anthropogenic pressures. In this study, the water quality of the Sabarmati River was assessed and analysed using secondary water quality data collected from the Central Pollution Control Board (CPCB) for a period of 12 years from 2012 to 2023. To determine the changes in water quality over the study period, annual mean values of temperature, dissolved oxygen (DO), pH, conductivity, biochemical oxygen demand (BOD), nitrate-N plus nitrite-N, fecal coliform, and total coliform were analyzed. The results indicated interannual variation among the parameters analysed. The temperature was relatively constant (27.3–28.5°C), and the pH was in the range of 7.0–8.1. DO declined from 6.3 mg/L in 2012 to 4.8 mg/L in 2023, reaching a minimum of 4.2 mg/L in 2021. BOD had large variations, and the maximum value of 34.63 mg/L was observed in 2018. Combined nitrate-N plus nitrite-N concentrations were below 1 mg/L in 2015–2022 and reached 1.84 mg/L in 2023. Mann–Kendall tests with Sen's slopes were applied to all eight annual series. DO and total coliform showed decreasing trends at the unadjusted 0.05 level ($p = 0.009$ and 0.028), but no trend remained significant after Holm adjustment for eight tests. Coliform results remain provisional pending verification of flagged Table 1 entries. The data from the CPCB also suggest that there are ongoing variations in water-quality conditions and instances of high levels of organic and microbiological contamination, highlighting the need for ongoing monitoring and management of the Sabarmati River.

Keywords: *Sabarmati River, CPCB, water quality, temporal variation, dissolved oxygen, BOD, conductivity, nitrate, fecal coliform, total coliform.*

1. INTRODUCTION

Water is one of the most critical resources of nature, providing livelihood, conservation of biodiversity, functioning of ecosystems, and socioeconomic development. Water constitutes almost 71% of the earth's surface, but only 2.5% of the water is freshwater, and only 1% of the freshwater is available in rivers, lakes, and shallow ground water for direct human consumption (UNESCO, 2024). The demand for freshwater is high, and the quality of surface water has significantly decreased due to rapid population growth, urbanization, industrialization, and climate change. Therefore, safeguarding fresh water resources is emerging as a priority issue for the environment worldwide and is directly related to the achievement of

Sustainable Development Goal (SDG) 6: Ensure the availability and sustainable management of clean water and sanitation for all.

Rivers are one of the most important sources of freshwater, providing drinking water, irrigation water, raw water for industry, water for fisheries, recreational opportunities, and hydropower generation and serving various aquatic ecosystems. But these ecosystems are under various threats due to anthropogenic activities such as the dumping and release of untreated domestic sewage, industrial effluents, agricultural runoff, and solid wastes. These pollutants affect the physicochemical and microbiological characteristics of river water, resulting in a reduction in dissolved oxygen, nutrients, organic load and eutrophication and disturbance of aquatic biodiversity (Saxena et al., 2011). Apart from human activities, seasonal variation, rainfall variation and river discharge variation are also significant contributors to pollutant transport and concentration, and therefore long-term monitoring is essential to manage water quality effectively.

India has one of the world's biggest networks of rivers, but the pace of economic development and urbanization has put unprecedented stress on these water resources. Over the last decades, due to the growing industrialization, the low quality of wastewater treatment, and the development of urban settlements, several major rivers have suffered significant water quality degradation. River monitoring, therefore, using physicochemical, microbiological, and hydrochemical testing, has become an indispensable part of monitoring and evidence-based policymaking for the river environment.

The Sabarmati River is one of the significant rivers of Western India, with its high ecological, economic, and cultural value. The river rises from the Aravalli Hills in the state of Rajasthan and then makes its way through the state of Rajasthan, passing through a length of 371 km, and Gujarat until it reaches the Arabian Sea (Shah & Joshi, 2017). The river provides an important supply of water for domestic and agricultural needs, industry, and provisioning ecosystem services and is also used for tourism and urban development, especially in Ahmedabad, with the implementation of the Sabarmati Riverfront Development Project. Despite these socioeconomic advantages, rapid industrialization, a growing population, and urbanization have significantly modified the river's natural hydrology. The loss of wetlands, alteration of the river, and higher releases of untreated municipal sewage, industrial effluents, and solid waste have reduced the river's natural self-purifying ability and have eroded water quality.

Various researchers have studied the water quality of the Sabarmati River using various analytical methods. In an assessment of the Water Quality Index (WQI), Shah and Joshi (2017) showed that the river quality in the urban section was poor, with the main contributors being untreated sewage, industrial effluents, and urban runoff. In the same way, Saxena et al. (2011) showed that there were also significant changes in different physicochemical and bacteriological parameters of the Sabarmati River with increased values of BOD, COD, and microbial contamination, which are not recommended for drinking water.

To further analyze the physicochemical and biological parameters at various sampling points in Ahmedabad, Qureshi et al. (2018) studied the water quality of the Sabarmati River during the various monsoons and found that the river water was not found to meet the criteria of class A, B, or C surface

water as set by the Central Pollution Control Board (CPCB), thus requiring a lot of treatment and disinfection before it could be used for domestic purposes. Similarly, Vaghela et al. (2018) created a Water Quality Index that involves physicochemical and microbiological analysis and concluded that untreated sewage discharge and industrial effluents, urban runoff, and inadequate sanitation are the major contributors to deteriorating river water quality, especially in highly urbanized areas.

More recently, integrated hydrochemical investigations have provided a more holistic view of the processes controlling water quality in the Sabarmati River. Chaudhari et al., 2026 used hydrochemical indices, heavy metal assessment, and multivariate statistical methods to prove that while the natural geological processes add to the chemistry of the rivers, anthropogenic activities are still the dominating factors, particularly in the Ahmedabad metropolitan area, for water quality degradation. Besides, the recent studies published in Discover Applied Sciences have emphasized the necessity to incorporate long-term environmental monitoring with hydrochemical evaluation to assist sustainable management of river basins under the increasing stress of urban and climatic changes (Chaudhari et al., 2026).

Overall, the literature available indicates that the Sabarmati River is experiencing ongoing degradation as a result of the increased urban and industrial development, domestic sewage discharge, and hydrological regime changes in the river. Although many studies have examined the physicochemical, microbiological, and hydrochemical characteristics of the river, most have been conducted at a single sampling event, season, or short monitoring period. Little is therefore known about long-term temporal variations in river water quality and the success of pollution control programs over the long term.

To fill this gap in knowledge, the present study examines the temporal changes in water quality of the Sabarmati River based on long-term monitoring data from 2012 to 2023. This study is designed to seek trends in water quality over a 12-year period for selected physicochemical water quality parameters, to assess the success of current environmental management initiatives, and to provide scientific data to inform river conservation and future water resource management.

2. METHODOLOGY

Secondary water-quality data of the Sabarmati River for 2012-2023 were sourced from the Central Pollution Control Board (CPCB) under the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India (Central Pollution Control Board, n.d.) . Selected physico-chemical and microbiological indicators were included in the dataset, such as temperature, dissolved oxygen (D.O.), pH, conductivity, biochemical oxygen demand (B.O.D.), nitrate + nitrite, fecal coliform and total coliform (Central Pollution Control Board, n.d.). The records available were retrieved and tabulated systematically in table 1. The annual mean values reported in Table 1 were plotted graphically for each parameter to help identify the water-quality trends and temporal changes. The recorded values were also compared with the CPCB criteria for water quality classes C and D for designated uses, which gave an idea of the overall condition and likelihood of pollution of the river . These parameters were chosen because they are pertinent to the assessment of important physico-chemical parameters, organic pollution, nutrient

enrichment and microbiological contamination. The rationale for including each parameter is described below:

1. **Temperature:** Water temperature affects physical, chemical, and biological processes in aquatic ecosystems and the distribution and survival of aquatic organisms (Chapman, 1996; Wetzel, 2001).
2. **Dissolved Oxygen:** The amount of dissolved oxygen is an important measure of river health. Dissolved oxygen concentrations for Class B waters should be ≥5 mg/L and for Class C waters ≥4 mg/L, according to the Central Pollution Control Board (2024).
3. **Biochemical Oxygen Demand:** Biochemical Oxygen Demand (BOD) is the amount of oxygen used by microorganisms to convert the organic matter. The Central Pollution Control Board (2024) has set the BOD value for good-quality surface water to be less than 3 mg/L.
4. **pH:** For surface water, the permissible pH range is 6.5-8.5, which indicates that the water should not be too acidic or alkaline (Central Pollution Control Board, 2024).
5. **Electrical Conductivity:** EC is a measure of the amount of salts dissolved in water and is frequently used as an indicator of salinity and pollution (Chapman, 1996; Wetzel, 2001).
6. **Nitrate and Nitrite:** Nutrient pollution and high levels of nitrate and nitrite in drinking water can cause health problems like methemoglobinemia (World Health Organization, 2022; Bureau of Indian Standards, 2012).
7. **Fecal Coliform:** Fecal coliform bacteria are used extensively as an indicator of the presence of fecal contamination and the possible presence of pathogenic microorganisms (World Health Organization, 2022).
8. **Total Coliform:** The presence of total coliform bacteria is a useful indicator of the microbiological quality of water and a measure of the effectiveness of sanitation and water treatment (World Health Organization, 2022).

2.1 Study Area:

The headwaters of the Sabarmati River are located at Tepur village in the Udaipur District, Rajasthan, 24.7670° N, 73.4500° E, at an altitude of about 762 m asl. It runs for about 371 km in the states of Rajasthan and Gujarat and flows to the Gulf of Khambhat (Cambay), Arabian Sea, near Dholera, Gujarat (22.2500° N, 72.3000° E) (Shah & Joshi, 2017).

Sabarmati is one of the main rivers in the west of India and is vital for its water for domestic usage, agricultural applications, industry, and ecosystem services. The river is also an important feature in Ahmedabad, where it has played a role in the development of the city's culture, economy, and society. The Sabarmati Riverfront Development Project has been responsible for bringing parts of the river into the limelight as major urban and recreational areas over the last few decades. But the water quality of the river has been put under a great deal of strain due to the fast rate of urbanization, industrialization, and the growing amount of wastewater discharged by the municipality, especially in the urban section that passes through Ahmedabad.

The Sabarmati River is a suitable choice for the study of long-term changes in surface water quality because of its ecological importance and the number of anthropogenic stresses that it experiences. In addition, the standardized monitoring data obtained by the CPCB under the National Water Quality Monitoring Programme (NWMP) allow for the assessment of temporal variations in important physicochemical water quality parameters. Hence, for the purpose of assessing long-term water quality trends and the effectiveness of environmental management efforts, the Sabarmati River was chosen from 2012 to 2023.

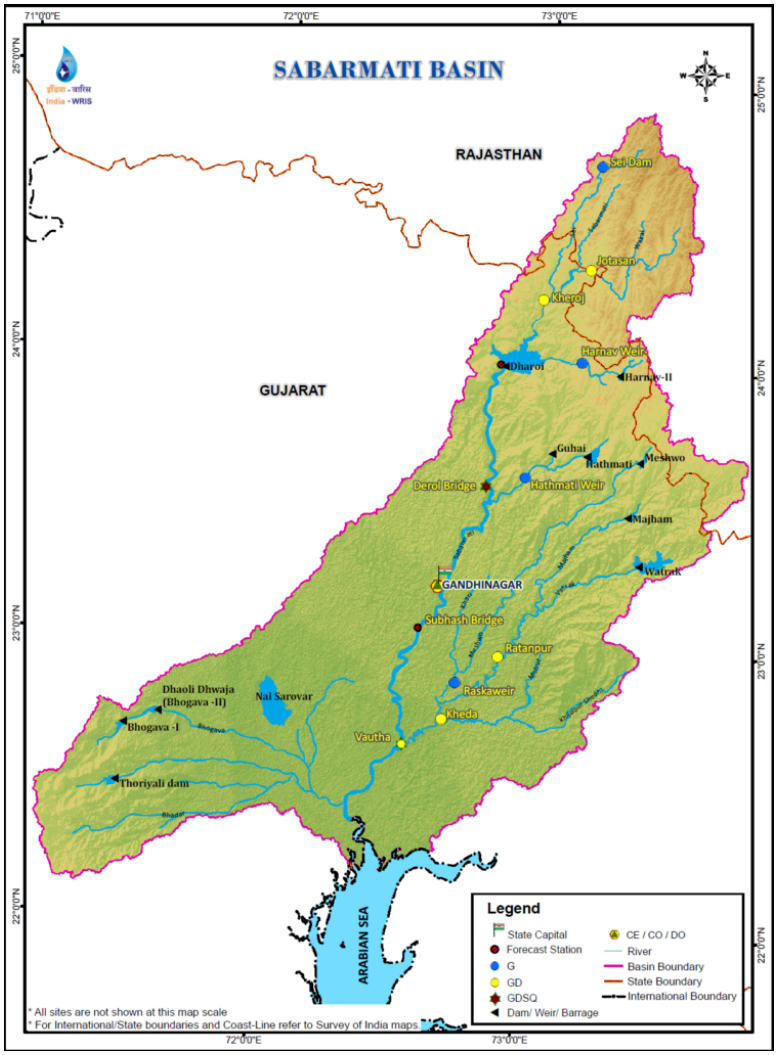

Fig. 1: Map showing the course and drainage basin of the Sabarmati River in western India. *Source:* India-WRIS (n.d.), National Remote Sensing Centre (NRSC), Indian Space Research Organisation (ISRO).

2.2 Ethical issues and safety considerations:

This study is based exclusively on publicly available secondary water-quality data obtained from the Central Pollution Control Board (CPCB), Ministry of Environment, Forest and Climate Change, Government of India. The data were accessed through the CPCB National Water Quality Monitoring Programme (NWMP) database: https://cpcb.nic.in/nwmp-data/. As the study does not involve human participants, animals, personal information, or primary environmental sample collection, no specific ethical concerns arise. Additionally, the study does not involve direct exposure to physical, biological, or chemical hazards, as the analysis is limited to existing publicly accessible data. Appropriate acknowledgement and citation of the CPCB as the data source have been maintained throughout the study.

2.3 Statistical trend analysis

Two-sided Mann–Kendall tests were calculated from the 12 annual values in Table 1 for each of the eight parameters, using a normal approximation with corrections for tied values and continuity. The statistic S is the sum of the signs of all later-minus-earlier value differences. Its variance is $[n(n-1)(2n+5) - \Sigma t(t-1)(2t+5)]/18$, where t is the size of each tied group. $Z = (S-1)/\sqrt{Var(S)}$ for $S > 0$, $Z = (S+1)/\sqrt{Var(S)}$ for $S < 0$, and $Z = 0$ for $S = 0$. Two-sided p-values were obtained from the standard normal distribution. Sen's slope was calculated as the median of all pairwise value differences divided by the corresponding differences in year (Mann, 1945; Sen, 1968).

An unadjusted significance level of 0.05 was used, and Holm-adjusted p-values were also reported for the eight simultaneous tests. The tests assess monotonic change, rather than all forms of interannual variation. No serial-correlation correction was applied; inference therefore assumes independent annual observations and remains exploratory with only 12 years of data. Python with NumPy and SciPy was used for the calculations. No missing or suspect value was replaced or interpolated.

The supplied files contain annual summaries but no station-level observations, sample counts, or aggregation worksheet. Consequently, the annual means and their weighting could not be independently reconstructed. The repeated coliform values and the rounded 2014 row are flagged in Table 1. Sensitivity checks excluded 2014 for every parameter and additionally excluded the flagged 2021–2022 total-coliform values and the 2022 fecal-coliform value, retaining actual calendar-year intervals.

3. RESULTS

Table 1: Reported annual mean values from 2012 to 2023 for water quality parameters of the River Sabarmati based on CPCB data

	Mean of the Physico-chemical Parameters/year							
Year	Temperature (°C)	DO (mg/L)	pH	Conductivity (µS/cm)	BOD (mg/L)	Nitrate-N + nitrite-N (mg/L)	Fecal coliform (MPN/100 mL)	Total coliform (MPN/100 mL)
2012	27.4	6.3	8.0	1478.45	14.670	7.8	445.9	2043.8
2013	27.3	6.2	8.0	1695.56	17.525	8.608	450.571	2220.222
2014	27.5	6.1	8.0	1250.0	19.5	4.1	360.0	2400.0
2015	28.3	6.5	7.8	895.30	6.631	0.517	33.720	1359.167
2016	28.3	5.8	8.0	1134.29	25.658	0.363	579.333	4678.742
2017	28.5	5.1	7.0	336.91	26.908	0.288	627.154	2458.538
2018	27.4	5.9	8.1	1202.50	34.625	0.274	187.850	985.450
2019	27.8	6.1	7.8	952.50	19.975	0.499	121.230	899.200
2020	27.8	5.2	7.8	943.13	23.838	0.918	453.042	1525.917
2021	28.5	4.2	7.8	1223.76	24.300	0.748	537.781	472.047
2022	27.9	5.5	7.7	985.34	16.168	0.638	472.047	472.047
2023	28.0	4.8	7.8	1010.65	10.210	1.840	580.120	690.230

Table 1 verification note: 472.047 MPN/100 mL occurs for total coliform in 2021 and 2022 and fecal coliform in 2022. These values are retained as supplied and are not confirmed as independent observations. In 2021, the reported total-coliform mean (472.047) is also below the fecal-coliform mean (537.781), warranting a check of transcription and sample comparability. The rounded 2014 entries are retained, but the underlying sample count is unavailable; rounding alone cannot establish whether they represent a single sample or an annual mean. Source records and the aggregation worksheet are required to resolve these issues. Trend estimates using these entries are provisional.

Table 2. Permissible range set by the CPCB for water classifications C (Drinking Water Source after Conventional Treatment and Disinfection) and D (Propagation of Wildlife and Fisheries) (Kapoor, 2024).

Parameter	Class C	Class D
Total Coliforms Organism (MPN/100ml)	≤ 5000	-
pH	6 - 9	6.5 - 8.5
Dissolved Oxygen (mg/L)	≥ 4	≥ 4
Biochemical Oxygen Demand (5 days, 20 °C) (mg/L)	≤ 3	-
Free Ammonia (as N) (mg/L)	-	≤ 1.2

3.1 Temperature:

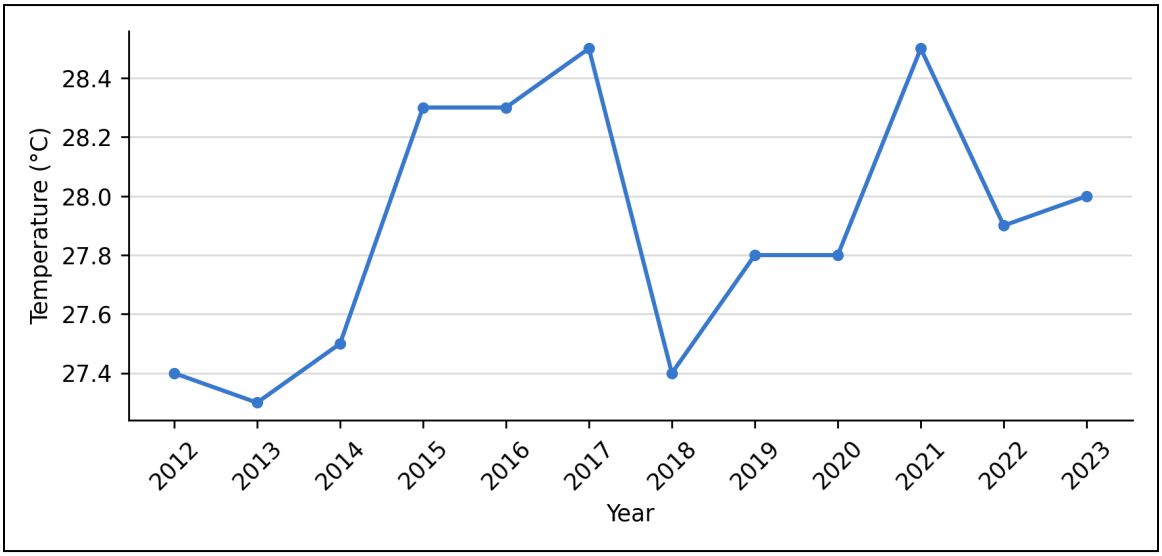

Fig. 2: Changes in the Surface Temperature of River Sabarmati from 2012 to 2023

Annual mean water temperature remained fairly consistent over the study period, ranging from 27.3°C (2013) to 28.5°C (2017 and 2021). The interannual fluctuations were small, indicating that water temperature was mainly controlled by regional climatic factors and not by a high degree of thermal pollution. The marginal increase in 2015-2017 and 2021 is probably attributed to the decrease in river water discharge, increase in solar radiation and the urban heat island effect due to rapid urbanization in the Ahmedabad region. Stable temperature conditions are extremely important because they affect the rate of biochemical reactions, the solubility of dissolved oxygen and the metabolism of microbes. Similar observations have been made by Saxena et al. (2011) who have reported relatively small seasonal variations for Sabarmati River water quality parameters, whereas other water quality parameters varied

significantly. The Mann–Kendall test gave p = 0.111 and Sen's slope = 0.05 °C/year. No statistically significant monotonic trend was detected at the unadjusted 0.05 level.

3.2 Dissolved oxygen:

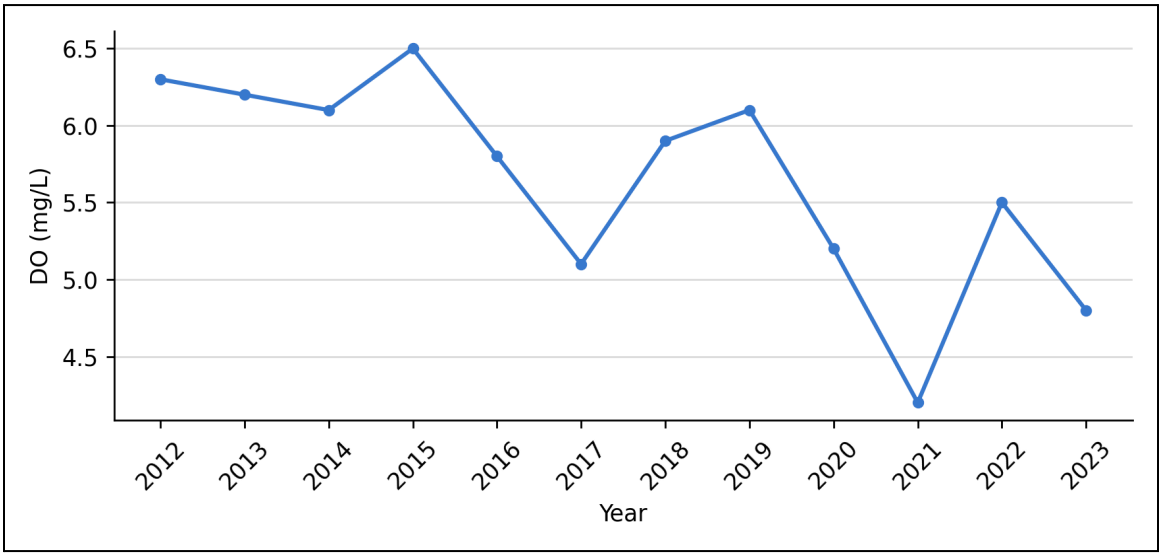

Fig. 3: Changes in the Dissolved Oxygen Levels of River Sabarmati from 2012 to 2023

The overall trend of DO was down, from 6.3 mg/L in 2012 to 4.8 mg/L in 2023, with the lowest annual mean value being 4.2 mg/L in 2021. The minimum dissolved oxygen concentration of surface water is 5 mg/L for Class B (outdoor bathing) and 4 mg/L for Class C (drinking water after conventional treatment and disinfection) as per the Central Pollution Control Board (CPCB, 2024) guideline. The concentration of DO in the study period generally exceeded the Class C criterion but fell below the Class B criterion in 2021 and 2023, indicating a gradual deterioration in the ecological quality of water. The decrease in dissolved oxygen may be due to the increased microbial decomposition of organic matter and increased oxygen demand from discharge of untreated domestic sewage and industrial effluents. A similar decrease in DO was also observed in the urban section of the Sabarmati River by Shah and Joshi (2017), which correlated with the growing anthropogenic pressure. Chaudhari et al. (2026) also found that the anthropogenic activities are still the dominant factor affecting the hydrochemical characteristics of the river. The Mann–Kendall test gave p = 0.009 and Sen's slope = -0.1369 mg/L/year. The decreasing trend was significant at the unadjusted 0.05 level, but not after Holm adjustment.

3.3 pH:

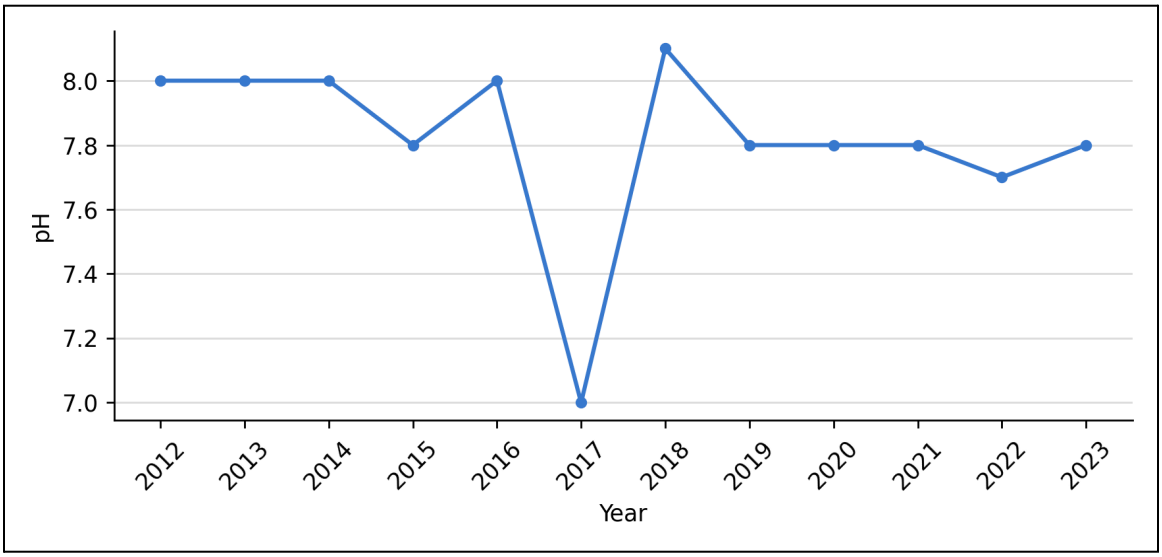

Fig. 4: Changes in the pH of River Sabarmati from 2012 to 2023

The river had a very consistent slightly alkaline pH range, which ranged from 7.0 to 8.1 and remained in this range for the 12 years of monitoring. The values were also within the permissible range of 6.5 – 8.5 given for Class A and Class B surface waters by the Central Pollution Control Board (CPCB, 2024) and within the permissible range of 6.0 – 9.0 for Class C waters. The stability of the pH indicates that the Sabarmati River has the potential to buffer against pH changes due to the addition of wastewater and changes in flow and levels throughout the year. Rivers flowing from semi-arid areas under carbonate-rich geologies exhibit these conditions. Similar findings were obtained by Qureshi et al. (2018) that, although it was highly polluted, the river still had acceptable pH levels during the Ahmedabad section. The Mann–Kendall test gave p = 0.093 and Sen's slope = -0.02222 pH units/year. No statistically significant monotonic trend was detected at the unadjusted 0.05 level.

3.4 Conductivity:

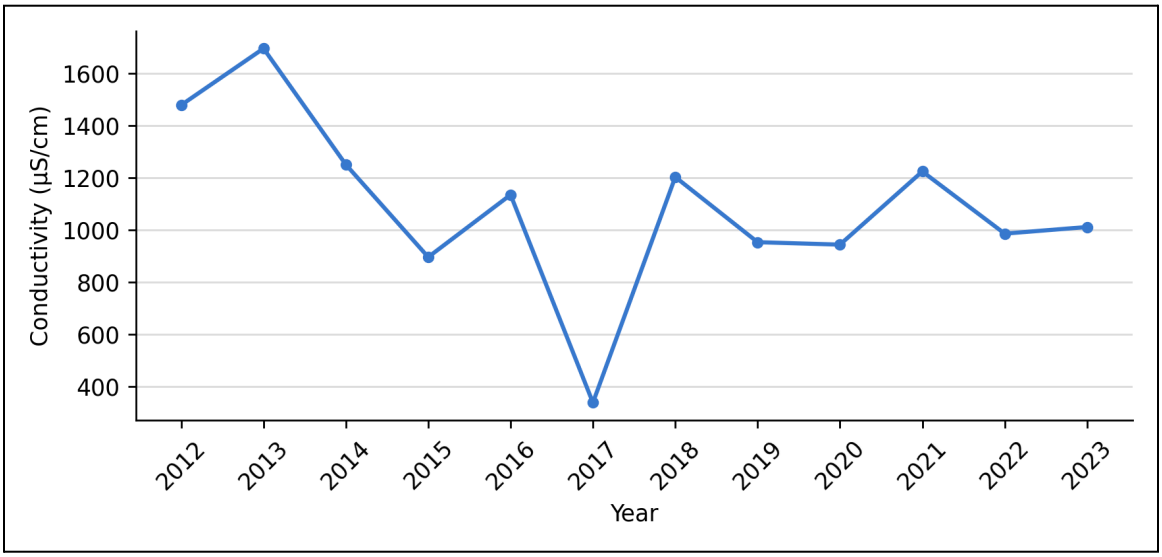

Fig. 5: Changes in the Conductivity of River Sabarmati from 2012 to 2023

There was marked interannual variation in electrical conductivity, ranging from 336.91 µS/cm in 2017 to 1695.56 µS/cm in 2013. Conductivity is indicative of the concentration of dissolved ionic constituents from domestic sewage, industrial effluents, and agricultural runoff. The ranges varied in each year, and all the annual means were below the maximum allowable limit of 2250 µS/cm recommended by the Central Pollution Control Board (CPCB, 2024) for irrigation water (Class E). The increase in conductivity in the first years of monitoring also indicates that there is more of an industrial and municipal discharge of dissolved salts, and the decline in conductivity after 2015 may be due to improved management of dilution and pollution. Saxena et al. (2011) also observed similar conductivity and blamed the dissolved solids from anthropogenic sources as one of the reasons for the poor water quality of the Sabarmati River. The Mann–Kendall test gave $p = 0.244$ and Sen's slope = -40.45 µS/cm/year. No statistically significant monotonic trend was detected at the unadjusted 0.05 level.

3.5 BOD

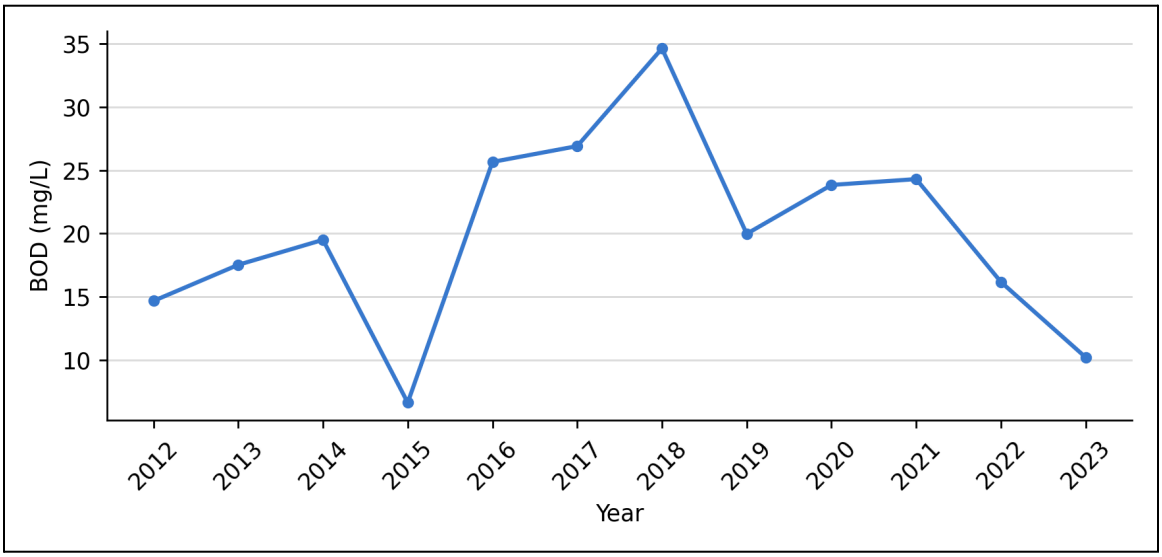

Fig. 6: Changes in the BOD of River Sabarmati from 2012 to 2023

BOD (biochemical oxygen demand) showed a non-monotonic pattern over the study period. Mean BOD increased from 14.67 mg/L in 2012 to a maximum of 34.63 mg/L in 2018 and fell to 10.21 mg/L in 2023, with fluctuations after the peak. While the reduction has been noticed since 2018, BOD values in all the periods of study were still much higher than BOD limits prescribed by the Central Pollution Control Board (CPCB, 2024) for Class A, B, and C waters, which are 2 mg/L and 3 mg/L, respectively. High BOD levels are considered to be persistent and are caused by the river receiving untreated sewage (domestic and industrial) and organic wastes in excess of its capacity. The reduction in DO is compatible with organic pollution, but these annual summaries do not establish the cause of oxygen depletion. Similarly, Shah and Joshi (2017) also found high BOD concentration in the Ahmedabad region as a result of untreated sewage discharges into the water, and Qureshi et al. (2018) concluded that organic contamination is one of the main contributors to the deterioration of water quality of the Sabarmati River. The drop in BOD since 2018 could be due to the improved management of the wastewater or better dilution, but the concentration is still far from the CPCB standards, showing that organic pollution is a major environmental issue. The Mann–Kendall test gave $p = 0.732$ and Sen's slope = 0.4279 mg/L/year. No statistically significant monotonic trend was detected at the unadjusted 0.05 level.

3.6 Nitrate + Nitrite:

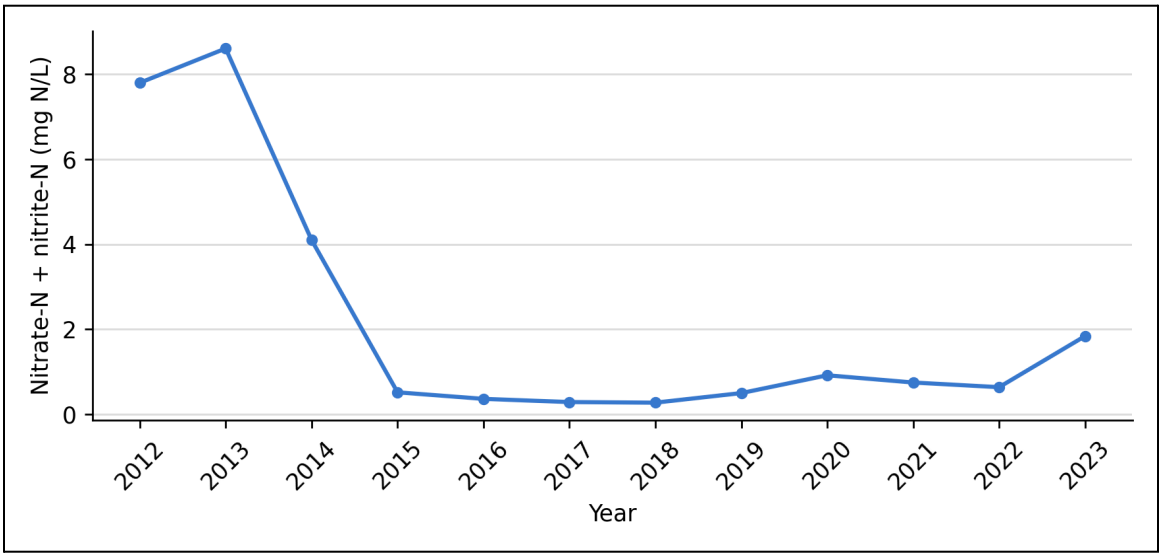

Fig. 7: Changes in the nitrate + nitrite of River Sabarmati from 2012 to 2023

The combined nitrate-N plus nitrite-N concentrations decreased from 7.8 mg/L in 2012 to < 1 mg/L in 2015–2022, and then an increase to 1.84 mg/L in 2023. The lower concentrations after 2014 could be due to better nutrient management, less agricultural runoff, better wastewater treatment or higher biological uptake in the river system. The combined nitrogen measure does not distinguish nitrate from nitrite and cannot by itself establish drinking-water safety or exclude eutrophication risk. Continued nutrient monitoring is therefore important. Similarly, Chaudhari et al. (2026) reported that the hydrochemical processes in the Sabarmati River are natural and anthropogenic. The Mann–Kendall test gave $p = 0.451$ and Sen's slope = -0.1123 mg N/L/year. No statistically significant monotonic trend was detected at the unadjusted 0.05 level.

3.7 Fecal Coliform:

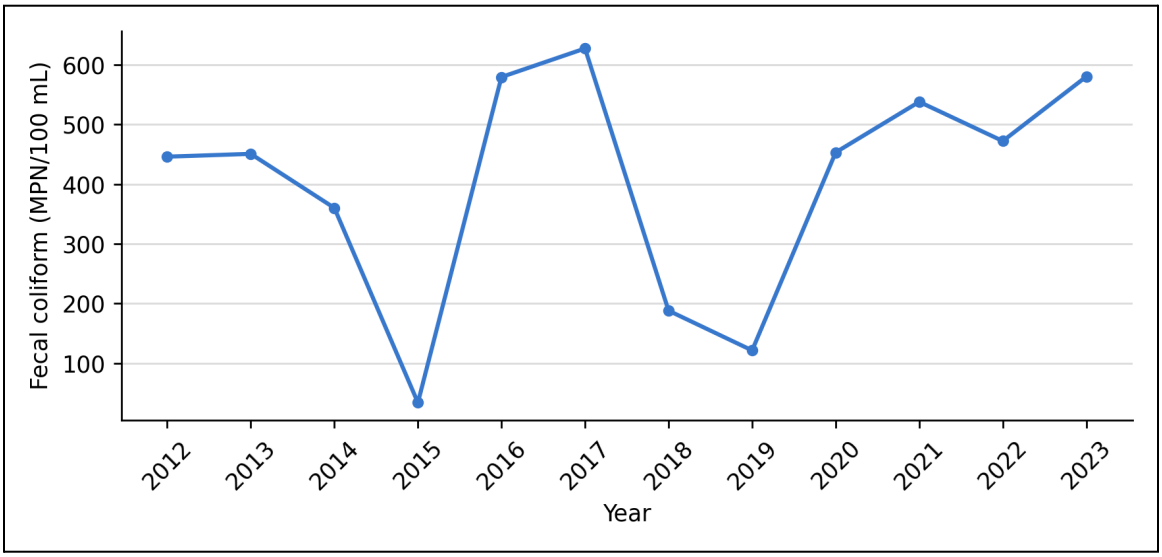

Fig. 8: Changes in the Fecal Coliform of River Sabarmati from 2012 to 2023

There was a marked interannual variation in the fecal coliform counts, ranging from 33.72 MPN/100 mL in 2015 to 627.15 MPN/100 mL in 2017. Fecal coliform counts exceeded 500 MPN/100 mL in 2016, 2017, 2021 and 2023, while all reported annual means were below 2500 MPN/100 mL. These comparisons describe the tabulated values and do not establish compliance at individual monitoring sites. High levels of fecal coliforms are a serious public health issue due to their possible association with pathogenic bacteria. Similarly, high bacteriological contamination of the Sabarmati River was also reported in the urban areas of high population density by Saxena et al. (2011). The Mann–Kendall test gave $p = 0.244$ and Sen's slope = 11.55 MPN/100 mL/year. No statistically significant monotonic trend was detected at the unadjusted 0.05 level.

3.8 Total Coliform:

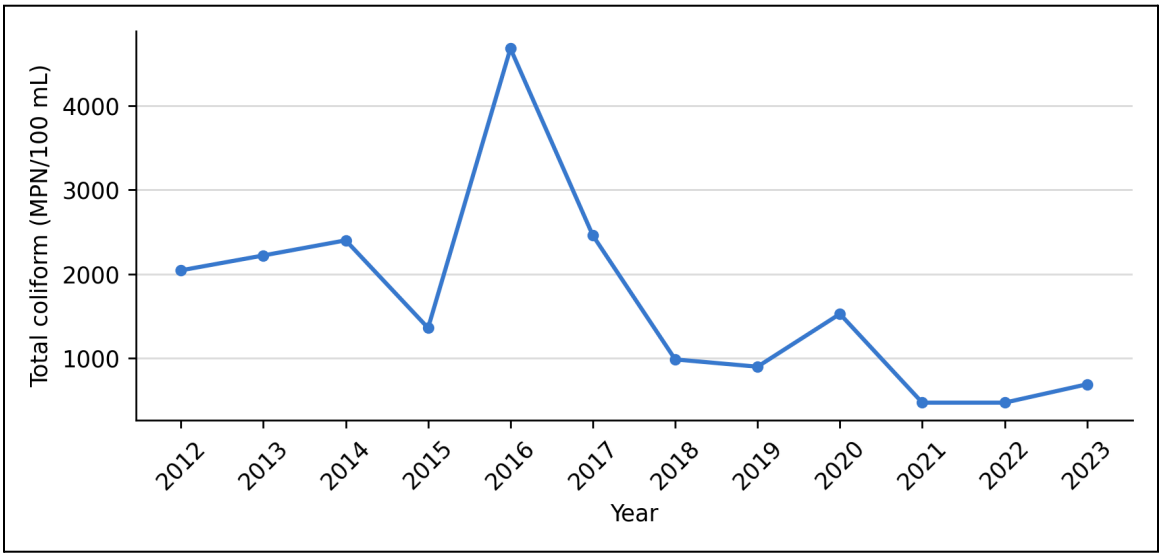

Fig. 9: Changes in the Total Coliform of River Sabarmati from 2012 to 2023

The total coliform counts fluctuated markedly throughout the study period, rising quickly to 4678.74 MPN/100 mL in 2016 and decreasing to 690.23 MPN/100 mL in 2023. The Central Pollution Control Board (CPCB, 2024) prescribes that the total coliform concentration should not be more than 5000 MPN/100 mL in Class C waters. Annual mean concentrations did not reach this level but were all above the Class A total-coliform criterion of 50 MPN/100 mL and exceeded the Class B criterion of 500 MPN/100 mL in every year except 2021 and 2022, reflecting continued microbiological contamination. Lower reported counts in several later years suggest a possible reduction in microbial contamination, but the flagged 2021–2022 values require verification and the data do not demonstrate that wastewater-management changes caused the decrease. Qureshi et al. (2018) also arrived at the same conclusion that microbial contamination is one of the major causes of inadequate quality of Sabarmati River water for domestic and recreational purposes. The Mann–Kendall test gave $p = 0.028$ and Sen's slope = -160.3 MPN/100 mL/year. The decreasing trend was significant at the unadjusted 0.05 level, but not after Holm adjustment.

3.9 Summary of trend tests

Table 3: Mann–Kendall tests and Sen's slopes calculated from the reported annual values in Table 1

Parameter	S	Z	p	Holm p	Sen slope/year
Temperature (°C)	24	1.592	0.111	0.557	0.05
DO (mg/L)	-39	-2.612	0.009	0.072	-0.1369
pH	-24	-1.680	0.093	0.557	-0.02222
Conductivity (µS/cm)	-18	-1.166	0.244	0.975	-40.45
BOD (mg/L)	6	0.343	0.732	0.975	0.4279
Nitrate-N + nitrite-N (mg N/L)	-12	-0.754	0.451	0.975	-0.1123
Fecal coliform (MPN/100 mL)	18	1.166	0.244	0.975	11.55
Total coliform (MPN/100 mL)	-33	-2.199	0.028	0.195	-160.3

Notes: n = 12 for each series; p-values are two-sided, tie-corrected and continuity-corrected normal approximations. S and Z indicate trend direction. Sen slopes use the units in the parameter column per year. None of the eight trends remains significant after Holm adjustment. Coliform results are provisional because of the flagged source-data issues in Table 1.

In the sensitivity checks, the unadjusted p-value for DO was 0.020 (n = 11) and that for total coliform was 0.118 (n = 9). No other parameter reached the unadjusted 0.05 level, and none remained significant after Holm adjustment across the eight sensitivity tests. These exclusions assess dependence on the flagged entries; they do not validate or correct the source data.

4. DISCUSSION

The purpose of this study is to comprehensively evaluate the long-term changes in the water quality of the Sabarmati River during 2012–2023 using CPCB data. The trends observed suggest that some physicochemical parameters were fairly constant during the study period, while the other ones continue to provide evidence of high anthropogenic influence on the river ecosystem. The findings strongly suggest that the combination of urbanization, industrialization, wastewater discharge, and river hydrology all play a crucial role in the ecological health of the Sabarmati River.

A major finding was the decrease in dissolved oxygen (DO) over the 12-year period. Dissolved oxygen is essential to the health of the river, as it influences the natural variety of the water and the river's ability to self-purify. The Central Pollution Control Board (2024) has prescribed a minimum level of dissolved oxygen to be 5 mg/L for surface waters for outdoor bathing (Class B). The concentration of DO in the

Sabarmati River was generally found to be higher than the minimum requirement for Class C water, but the downward trend suggests the possibility of increased oxygen depletion with an increase in organic loading. Shah and Joshi (2017) also reported the reduction in Sabarmati River's DO in the urban areas of the river, which is attributed to the discharge of untreated municipal sewage and industrial effluents and the reduction in river flow. The same trend can be noted in other highly urbanized rivers of India, where excessive organic matter and wastewater discharge have been seen to significantly lower oxygen availability and have a detrimental impact on the aquatic ecosystem (Chaudhari et al., 2026) .

The most important parameter which showed the deterioration of water quality throughout the study period was the Biochemical Oxygen Demand (BOD), which was always found to be higher than the prescribed BOD limits by CPCB. The higher BOD values recorded from 2012 to 2018 indicate that there could be a significant inflow of biodegradable organic material, mainly due to domestic and industrial effluents. BOD peaked in 2018 and was lower by 2023, although it fluctuated in the intervening years. Every annual mean exceeded the recommended BOD level of 3 mg/L for Class B and Class C waters (Central Pollution Control Board 2024). The full-period Mann–Kendall test did not detect a significant monotonic BOD trend ($p = 0.732$). Microbial respiration rates are accelerated with high BOD levels, and low DO levels may negatively affect aquatic life. The same has been reported by Qureshi et al. (2018), who reported that untreated municipal wastewater is one of the major sources of organic pollution in the Sabarmati River. The high BOD was also reported by Saxena et al. (2011), and the high bacterial contamination was also reported, which indicates that the river basin has been facing the problem of organic pollution for more than 10 years.

Unlike other parameters, the pH of the river remained in the limit prescribed by CPCB during the monitoring period. The slightly alkaline nature of the river is a common phenomenon in many rivers of the semi-arid region of western India and is attributed to the nature of the river basin and the natural buffering process. The river water pH values are relatively stable, suggesting that several factors of water quality are affected by anthropogenic activities, but they have not significantly altered the acid-base balance of the river. In past studies conducted on the Sabarmati River, the water quality showed significant degradation in other water quality parameters, yet the pH values were still found to be within the permissible limits (Shah & Joshi, 2017; Qureshi et al., 2018).

The water's electrical conductivity showed a great deal of variation over time during the study period, which is related to variation in the concentration of dissolved ionic substances. High conductivity is usually a result of higher levels of dissolved salts from industrial effluents, domestic wastewater, and agricultural runoff. The highest conductivities occurred in the first few years of monitoring and then slowly decreased and fluctuated. The conductivity of the waters was found to be lower than the maximum recommended limits for irrigation waters by the CPCB, but the variability observed showed that there has been a change in the pattern of industrial discharge, seasonal dilution, and regulation of river flow. Dissolved ionic pollutants also continue to affect the chemistry of the river, as Saxena et al. (2011) reported high conductivity levels in certain parts of the Sabarmati River where there is no treatment of industrial and municipal effluents.

Combined nitrate-N plus nitrite-N concentrations were lower after 2014, although the full-period monotonic trend was not statistically significant ($p = 0.451$). Nutrient enrichment is commonly linked with agricultural runoff, domestic wastewater, and industrial effluents and may lead to eutrophication if they are present at high levels. The reduction in combined nitrate-N plus nitrite-N concentrations may have been attributed to better wastewater treatment, reduced inputs from agriculture to the monitored catchment and increased uptake by aquatic vegetation.Chaudhari et al., (2026) further reported that the natural hydrochemical processes and anthropogenic activities influence the hydrochemical condition of the river Sabarmati, and integrated management of the watershed is essential to maintain the nutrient balance.

Persistent contamination of the Sabarmati River was observed during the period of the study with the help of microbiological indicators. Fecal coliform and total coliform counts were both showing marked interannual variations, which suggested intermittent sewage breakdown and a range of wastewater management systems' effectiveness. The reported fecal coliform annual means ranged from 33.72 to 627.154 MPN/100 mL, exceeding 500 MPN/100 mL in 2016, 2017, 2021 and 2023. The repeated values flagged in Table 1 limit interpretation of the microbiological results. Similarly, total coliform counts were elevated relative to the Class A criterion and were lower in several later years, with intervening fluctuations. Bacteriological contamination is always a major constraint that affects the quality of the Sabarmati River for domestic and recreational purposes and has been detected during various investigations (Saxena et al., 2011; Qureshi et al., 2018). The results highlight the importance of further investments in sanitation facilities, efficient sewage treatment, and periodic microbiological monitoring.

The long-term trends of this study show that the Sabarmati River is still under anthropogenic stress; however, there are improvements in some water quality parameters at a local scale. The relatively stable natural hydrochemical background conditions suggest a fairly stable natural hydrochemical environment, while the high concentrations of persistent organic pollution, decreasing dissolved oxygen levels and periods of microbial contamination strongly suggest that the river ecosystem is still under a high level of environmental stress. The lower values of some pollutants in later years may reflect changes in dilution or wastewater inputs; the present dataset does not establish the effect of the Sabarmati Riverfront Development or wastewater-management interventions, but some pollutants, like BOD, are yet to meet the CPCB norms, and additional measures are needed to protect the ecology of the river. To achieve sustainable improvement in the water quality of the Sabarmati River, the long-term monitoring programmes, better control of industrial effluents and better sewage treatment plants will be needed, along with integrated river basin management strategies.

5. CONCLUSION

The water quality data obtained from the Central Pollution Control Board (CPCB) were used to analyse the long-term trends of water quality of the Sabarmati River from 2012 to 2023. The findings indicated that most of the parameters associated with organic and microbial pollution were still of concern in the environment, while the rest associated with temperature and pH were relatively stable and within acceptable limits. The reported annual values indicate continuing organic pollution, with a decrease in

dissolved oxygen, high biochemical oxygen demand and fluctuating concentrations of total and fecal coliform.

The observed deterioration in water quality as compared to previous studies is similar to the long-term effect of rapid urbanization, industrialization and municipal sewage discharge in the Sabarmati basin. Some parameters, such as nitrate concentration and conductivity, have improved in the second half of the study, whereas the continuous failure to meet the CPCB standards in BOD indicates that the measures taken for pollution management and the sustainable management of the river need to be more efficient.

The study has certain limitations, such as secondary data collected from the monitoring stations of CPCB and analysis of only a few physicochemical and microbiological parameters. Seasonal variations were not included in the analysis, and emerging pollutants such as pharmaceutical residues, pesticides, microplastics and spatial variability were not analysed in detail. The results must be interpreted bearing in mind the above. The unverified repeated coliform values and rounded 2014 entries, unavailable station-level sample counts, possible changes in monitoring coverage and unassessed serial dependence further limit inference. Annual averages can conceal local exceedances and cannot establish designated-use compliance for every station. The statistical results are exploratory; no trend was significant after adjustment for eight tests.

Future studies are recommended to incorporate long-term monitoring, Water Quality Index (WQI) analysis, GIS-based spatial analysis and multivariate statistical analysis to gain insight into the river health changes over time and space. In addition, the integration of emerging contaminant factors, aquatic biodiversity investigations, and systems capable of real-time water quality monitoring and incorporating IoT would provide a more complete understanding of the river ecosystem and provide evidence-based environmental management.

In conclusion, this study reveals the impacts of water quality changes in the Sabarmati River and emphasizes the need for ongoing monitoring, enhanced wastewater treatment facilities, and robust policy enforcement to safeguard the river's long-term water quality and sustainability.

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